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Appendix to the

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Subject Matter Suitable for a Two-year

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Subject Matter Suitable for a Two-year Non-Concentrator Course in the Natural Sciences

As a contribution to general education, a course in the natural sciences should be devoted to the purely intellectual aspects of the subjects involved. The present knowledge of the methods, the laws and the conceptions of the sciences should be disseminated among as many persons as possible. It is to be hoped that the realization of this wider understanding will prove of value to those engaged in the arts and letters, contemporary history and philosophy and the social sciences and to those whose responsibilities will be in the domain of public affairs.

Concepts and Laws of the Exact Sciences

The course would begin with the study of the fundamental laws of motion and the demonstration that an exact science of mechanics, valid for both the motion of bodies on the earth and throughout the universe, is possible. As a sequel to this discovery there are two developments, the science of great distances, modern astronomy, and the science of sub-microscopic distances, modern physics and chemistry.

The motion of heavenly bodies, the distance in and beyond the solar systems, the dimensions of the Milky Way and the distances of galaxies would be suitable astronomical topics. In this development, the physical and chemical properties of astronomical bodies would find their place and energy generation in stellar interiors would be discussed. It is safe to state that no possible leap of the human imagination could have conceived a more awe-inspiring

and fantastic observable universe than the expanding one which scientists have found as the result of their incessant labor and invention.

No less remarkable is the twentieth century discovery that an exact mechanics of sub-microscopic atoms and molecules is possible. Following the discovery of the nature of light and electricity a theory of the structure of atoms has been developed which has proved to be a powerful vehicle for explaining the order of the chemical elements found by the nineteenth century scientists. The nuclear theory of atoms provides a basis not only for explaining the familiar chemical reactions in our immediate environment but also the reactions which take place in the stars. Today the nuclear scientists are carrying out in miniature for the first time on this earth the reactions whose energy release produces stars. Thus for one to whom such concepts are not foreign, it is easy to accept without too much wonderment the statement that one cubic inch of uranium as a fuel is equal to millions of pounds of coal.

Another theme which can be taught without recourse to mathematics and which helps to bridge the gap from the exact to the biological sciences and medicine is structural chemistry. Beginning with the spatial arrangement and the accurate measurements of the distances between the atoms in crystals, this subject can be extended from the knowledge of the tetrahedral nature of the carbon compounds and synthetic organic chemicals to the naturally occurring organic substances. This subject can be amply illustrated by spatial models not only of compounds whose structures are known with certainty but also of substances of vast complexity such as proteins, the structures of which are only partially conjectured. Such illustrations of the

present frontier of the structural knowledge of substances should communicate to the student the spirit with which thousands of chemists are attacking the intricate problems which are so closely connected with the future of biology and medicine.

The Earth and Its Inhabitants.

This course would utilize the ideas of time, space, motion and matter derived from physics, astronomy and chemistry by showing how they operate at new levels of complexity and organization. The age of the earth, now measurable by the methods of physical science, the record of life confined to the latter half of its existence, and that of Man to the last .0005 of earth's existence as a separate planet are facts essential for a reasonable perspective in time and space of the human adventure. Only through knowledge of this kind can we hope to counteract the megalomania which leads to a costly disregard of man's place in nature and the attendant obligations.

The whole key to the development of geology and the inseparable doctrine of organic evolution lies in the idea of uniformitarianism, the formulation of which, despite its simplicity, was revolutionary in human thought. The idea that changes of the past are explainable in terms of processes observable today has not only proved to be a powerful working tool, but an immense liberator of the human mind as well. The exposition and application of this idea would, of course, be an integral part of the program in question.

Form as an expression of organization is one of the fundamental problems of the biologist. This can be conveniently and properly

introduced by a study of the fossil record, culminating in an examination of selected living forms. From these one can proceed to a consideration of the innate qualities of living stuff and those processes of the environment whose resultant has been evolution.

The very fact of organization is an expression of the multiple relationships of living beings and the complex of conditions necessary to their activity. In the study of organisms the simple either/or approach, a dangerous fallacy in dealing with the problems of modern social, political, and economic life, has to be discarded. The intellectual experience of viewing phenomena in which limiting factors rather than simple causality operate is certainly one of the most important contributions that can be made by a study of the earth and its inhabitants.

Contingent upon this is a concept which is today most fruitful in research and which bridges the gap between the physical and "natural" sciences, or to use the classical terms, between natural philosophy and natural history. This is the concept of life at all levels, from the single organism to the highly integrated community, as an expression of the flow and transformation of energy and materials. For the elucidation of general conceptions which involve matter and energy, biologists have recourse to the laws of thermodynamics which define exactly the equilibrium states of all matter and their corresponding energy relations, and the more recent generalizations of irreversible thermodynamics which treats in an exact manner the flows of heat, matter and electricity. The recognition of and respect for the generality and power of prediction of these laws as well as the laws of the two other exact sciences, mechanics and electrodynamics, are

essential aspects for the full comprehension of modern thought.

Liberal education is today threatened by two powerful extremes of doctrine. On the one hand is the paralyzing notion that man is merely the passive receptor of "conditioning" experiences for which he has been in no way responsible. On the other hand is the idea that he is free to do anything he wishes, using his knowledge of natural law merely as an instrument of aggrandizement, instead of a source of perspective upon himself and an augury of his future on this earth.

All these observations suggest that a realistic appreciation of the long geological and biological background of mankind, conditioned at every step, yet marked by ceaseless struggle and effort and at length by superbly beautiful adjustments - within the organism, between organisms, and between communities and environment - and holding the promise of a creative equilibrium is a long step toward the Golden Mean of the liberal mind.

Natural Science and Crucial Contemporary Problems

Knowledge of these and kindred topics and cognizance of the magnitude and vitality of scientific activity in the natural and social fields are essential for a thorough understanding of modern civilization. The ideas and generalizations of basic science sometimes in apparent ways, sometimes in subtle manners are penetrating every phase of contemporary thought. But beyond these intellectual contributions lie two more sombre issues, the uses or misuses of discoveries and subsequent inventions and the restrictions imposed by the natural resources t

of the earth. [illegible] decisions regarding these great issues that general [illegible] in the sciences can fulfill the purpose of developing a more enlightened citizenry.

The most important peaceful use of atomic energy, the development of large scale power production from nuclear fuel, has received great publicity as a result of President Eisenhower's recent dramatic proposal to the United Nations. If the plan for pooling the scientific and natural resources of some or all nations is accepted, then any agreement must be ratified by the Congress of the United States, most of whom have no fundamental knowledge of nuclear processes and the multiplicity of technical and economic factors involved. We trust that the future graduates of Yale, many of whom will attain positions of public policy making, will either have acquired knowledge of this kind or by virtue of their education and interests will possess the means to obtain knowledge of this kind independently and without briefing.

It is appropriate to conclude this survey with a subject which embraces all the sciences, the humanities and the policy makers. It is estimated that the human population of the earth is increasing at the rate of seventy thousand persons every day. The earth is a large place but it is finite. It is therefore safe to assume that of the many resource materials necessary for sustaining the present or increased population, there will be some vital ones which will be depleted more rapidly than others. In informed circles concern is being stressed regarding the long range supply of phosphate rock in the United States. Phosphates in some form are necessary in fertilizers to supply ultimately the material for bone formation and are thus indispensable for the life

of biological species including man. At present, enormous quantities of fertilizer phosphate are processed from the rich mineral (apatite) ores in Tennessee and Florida. These are the only two now known rich phosphate deposits in this country and at the rate at which they are being consumed may be exhausted in a few decades. The processing of low grade deposits such as those in Idaho will be much more difficult and the cost of future phosphate fertilizer much greater.

Natural science is the only knowledge which permits anticipation of world necessities like this one and the attempt to master it involves the experience of men in all the fields of pure and applied natural science. To the physicists and engineers we must look for the new sources of energy for power production. On the chemical engineers we must rely for the design of equipment and on the chemists for improved methods of processing of the ores. By their researches, the chemists and plant scientists are striving to improve the absorption by plants of phosphate because a large percentage of this material is lost in farming. Some day, this problem will be an acute one in this country and today it is an acute world problem. We can only hope that the geologists keep finding more source material.

The subjects of nuclear energy and of the nutrition of populations have been chosen as illustrations because the wise exploitation of either of them is essential for a rational future civilisation and their maltreatment by ignorant and irresponsible persons can only lead to destruction and famine. When public emergencies of these kinds arise, the natural scientists are called for consultation. Rarely has their knowledge been used to forestall emergencies, and still

more rarely have they risen in a body as they did just after the first atomic explosion to demand effective legislation of the kind which resulted in the formation of the Atomic Energy Commission. It is not to be expected that masters of science like Benjamin Franklin will be found in Congress and in high policy making positions but it would be very advantageous for those whose responsibility it is to dispense funds to understand the importance of basic science and its relation to the great issues. It is through such knowledge that wise judgments can be made and good legislation enacted without prejudice and partisanship.

A sequence of courses which begins with the fundamental concepts of physics and chemistry and develops consistently from the exact through the natural sciences to the problems which plague the man of public affairs will offer many difficulties in its presentation. For the maximum of success its teachers must not only know science but should be successful scientists. Profound knowledge will be required for the wise selection of material and success in science will be necessary to sustain the enthusiasm of presentation. The task of imparting this knowledge is a difficult one which will require rare gifts but it can be accomplished.